Acoustic Sensing for Area Protection

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ABSTRACT

This paper is an overview of the acoustic means developed by 01dB-METRAVIB for ***area protection****. This topic involves multi-sensors (acoustic, seismic, video camera, radars, perimetric sensors…), signal processing for intelligence surveillance and reconnaissance applications, as well as fusion, in order to achieve good detection performance with low false alarm rates while reducing the requirement for human resources.*

Regarding ***multi-sensor developments****, and for more than ten years, from the Bosnian to the most recents conflicts, the company has acquired a lot of experience in the area of acoustic systems for detecting and locating various threats (small arm fire, mortar fire, vehicle, helicopters, aircrafts, etc.). Combat-proven, the PILARw products are now used by many Armed and Security Forces around the globe. A complete observation system (PIVOT) interfaced with PILARw allows threat recognition and visual tracking. For vehicle and personnel detection, PILARMAN and SNAKE systems have been evaluated. 01dB-METRAVIB is now integrating the Oper@ wireless technology initially developed for environmental noise monitoring in order to provide a complete sensor suite for acoustic detection.*

Recent ***advances in acoustic signal processing*** *supported, in part, by the French DGA, allow detecting, locating, tracking, classifying and reporting of potential threats in real-time. The main algorithm improvements include: false alarm reduction, multi-target localisation based on high-resolution array processing, tracking technique, target recognition and data fusion.*

For defence applications, the company has been developing an acoustic concept based on ***unattended ground sensors organised in clusters*** *with the benefit of multi-sensor developments and of advanced signal processing. Each cluster is composed of a suite of acoustic and seismic sensors distributed over the controlled zone. A technology including structured multi-sensor, wireless communication capability and advance data processing constitutes an innovative solution for area protection.*

For ***homeland security*** *the developed systems can be used for border surveillance as well as for securing events and installations against terrorist attacks. The various applications include international conferences and popular meetings, building protection, airport protection, vehicle protection (VIPs, convoys, etc.).*

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1.0 INTRODUCTION

Acoustic surveillance presents considerable advantages: passive by nature, omni directional, all-weather capability, Non Field of View and Non Line Of Sight capacity, robust and low cost in mass production. Acoustic information, associated with seismic, magnetic and video images, offers powerful means for attended or unattended ground sensors (UGS).

The information generated by various threats (small arm fire, mortar fire, vehicle, helicopters, aircrafts, etc.), measured by different transducers (acoustic, seismic, video camera, radars, perimetric sensors, etc.) can be processed to provide reliable and actionable information. Corresponding signal processing was recently boosted by digital processing techniques and devices. It allows achieving fusion with low rates of false alarm for detection and with precise localisation, thus reducing the requirement for human resources. Therefore, intelligence surveillance and reconnaissance on battlefields (urban battlefields, peacekeeping areas and border surveillance) are today reinforced by the available multi sensing development.

The purpose of this paper is to show the means developed by 01dB-Metravib for area protection. For more than ten years, the company has acquired a lot of experience in acoustic systems and digital processing techniques for detecting and locating threats. These means deal with multi-sensor system development and signal processing including data fusion.

2.0 MULTI-SENSOR DEVELOPMENT

Based on its expertise in acoustics and signal processing, 01dB-Metravib has developed monitoring systems for the gunshot detection and localisation, as well as for environmental acoustic survey.

The company has developed a range of products for military and civilian applications, including possible coupling with surveillance systems and integration into different mobile platforms. We are also involved in research programs and prototype development. Threat detection algorithms for intrusion detection or border surveillance, as well as UGS, are in the scope of our projects.

This section presents the mains sensor developments that can be used for area protection.

2.1 PILARw

The PILARw system consists of 3 main components that are combined to create a number of different configurations, each with specific features:

- a foldable Acoustic Sensor Array (ASA) with embedded sensors and electronics,
- a Data Interface Acquisition Module (DIAM), which processes the signal of the array(s) in real time,
- a rugged or military standard PC (Laptop) to control the system and display results using Shotguard, the PILARw operating software

The PILARw system exists in two configurations: Ground based and Vehicle mounted. Because the specificity of each application requires specialised settings – such as background noise cancellation for vehicle-mounted applications, the DIAM includes several software tuned algorithms.

From the detection of acoustic waves of the passing bullet (Shock Wave) and the firing weapon (Muzzle Blast), the system yields and records threat position (azimuth, elevation, range, bullet trajectory), using arrays processing algorithms.

PILARw systems have been used by special and armed forces of many countries (USA, United Kingdom, Italy, Australia, France, etc.) during missions in outdoor operations. These systems then meet the highest requirements resulting from their use on the battlefield. In particular, they were granted US Army certifications M1 and M2 for Ground and Vehicle versions, respectively.

Due to changing conflicting situations, these systems have evolved to also allow for the detection of other threats such as rockets (RPG), missiles and mortars. Adaptation to other platform like helicopters have been studied.

As for prevention of operational risks, there is a broad range of applications: sniper detection and localization, protection of bases and sensitive buildings, protection of vehicles and convoys, security of public events, VIP protection, and border surveillance.

2.2 PIVOT

PIVOT (Pilar Versatile Observation Turret) is a rapid deployable man-portable system composed of a pan-and-tilt turret equipped with a day/dawn camera driven by a control unit with a high resolution and high brightness LCD display. PIVOT can be used as a stand-alone surveillance system or in combination with PILARw. In the later case, PIVOT will rotate and tilt according to PILARw instructions in the proper direction to provide an image of the shot origin in real-time.

2.3 PILARMAN

The PILARMAN system is a passive, ground-based acoustic detection, localisation and classification system for the individual soldier. The system is designed to detect and locate the presence of potential hostile intruders. It aims at detecting the multiple threats, which can arise on the battlefield, beyond the line of sight or the front line. PILARMAN detects and locates fire from small arms (5.56 to 20 mm) and ground vehicles (idling or moving). The system classifies the detected ground vehicles as, either tracked or wheeled.

The system can be deployed anywhere in a tactical environment to support reconnaissance missions, observation, incursion and target acquisition operations. Feasibility of integration of the sniper detection into the future soldiers equipment has been proven by integrating the sensor on the soldier vest.

2.3 SNAKE

SNAKE is an unattended ground system designed to detect the presence of a vehicle within a relatively narrow field of view in order to trigger a camera or similar device.

As a UGS, the system lies on the ground under a passive surveillance mode with very low current consumption. When an event is detected, the system analyses the data to confirm the presence of a vehicle within the field of view. When the outcome of the processing is positive, a TTL output signal is provided to trigger an external device.

The driving parameters of the detection (threshold, response time…) are adjustable from a laptop and dedicated software connected to SNAKE via an RS232 interface.

2.4 OPER@

The Oper@ system is the technical solution used to ensure acoustic monitoring of the environment, as well as area protection (threat detection). Oper@ consists of compact noise stations, allowing continuous acquisition of time and frequency signals. It is composed of associated Oper@-EX and Oper@-RF stations. The Oper@-RF stations, connected to one microphone (acoustic sensor) or one geophone (seismic sensor) are slave stations while the Oper@-EX is the master station.

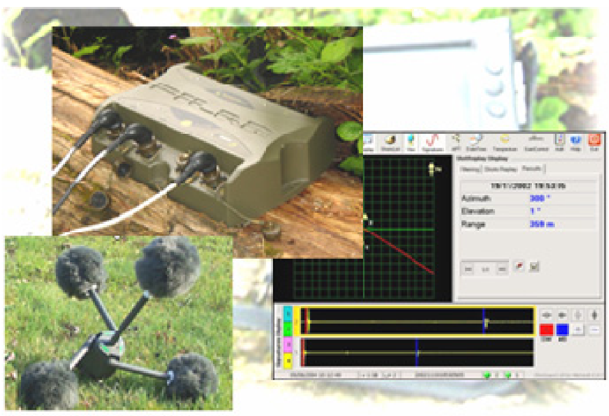
Oper@ is based on wireless technologies allowing for the real-time transmission of acoustic data, hence for a continuous monitoring of all on-site acquisitions by the operator, from a central workstation.

Wireless communication using radio frequencies are a now strong and reliable method over long distances. The Oper@ solution associates a host station called “area server” made up of Oper@-EX with several slave stations (up to 10 slave stations): the Oper@-RF stations.

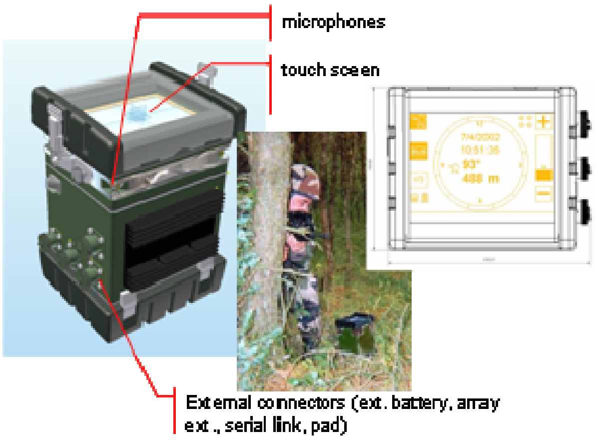
Each station includes a Digital Signal Processor (DSP) to perform the processing of the sampled signal. Oper@-RF stations measure sensor signals (microphone or geophone) in real time and continuously process parameters to characterise the noise source: Leq, Lp, third octave spectra, etc. The station can also send an alarm when an acoustic event is detected. All these data are sent in real time to the Oper@-EX station, which stores and transfers them to the main computer, using a protocol like ADSL or Network LAN. The “area server” can also support processing software for data fusion, for combination of acoustic and seismic information.

The measurements microphones, as well as the stations, can be installed outside in rural or in urban settings, by means of fixing accessories (wall fixing kit, strap). They are used for acoustic environmental survey (airport dynamic noise observatory) and are also well suited for surveillance (battlefield, border …).

2.5 Systems pictures



PILARw	PIVOT



PILARMAN

SNAKE

OPER@

Sensors

Figure 1: multi sensors developments

3.0 ADVANCES IN ACOUSTIC SIGNAL PROCESSING

Recent advances in research on acoustic signal processing carried out by the company have allowed detecting, locating, tracking, classifying and reporting potential threats in real-time. This work was supported, in part, by the French DGA [1].

On the battlefield, the targets of interests depend on the mission plan, detection of personnel (troops on the move), ground targets (single and multiple vehicles in convoys), airborne targets (helicopters, jets, cruise missiles, drones), and transients (gunshot, mortar or artillery, etc.). Depending on the targets, the emitted signal noise is of different nature. Gunshots generate impulsive signals, while vehicles generate quasi-stationary signals. Corresponding signal processing algorithms are then different.

Usually detection information includes localisation, tracking and recognition. Robust target information can be obtained by fusing information from different sensors located at various positions. Fusion is the key to the fidelity and accuracy of the UGS. For example, fusing acoustic, seismic and IR information improve classification and identification, and fusing bearing information from different UGS can be used to triangulate and estimate target location (with the distance).

3.1 Target detection

The target detection implemented on our detection systems is based on detection theory [1]. The method uses a detection threshold applied to physical measurements. Generally this threshold is set in relation to the signal-to-noise ratio and may be adjusted according to the ambient noise.

On UGS, the detection is either computed from a single sensor (microphone or geophone) or from a macro-sensor (acoustic array). Using an acoustic array, the signal-to-noise ratio is increased and then, gives a better detection range, as compared to a single sensor.

For quasi-stationary targets (vehicle, jet, helicopter), the acoustic and seismic waves consist of frequency harmonics due to the engine and of background noise. Detection is performed on the filtered waveform. For impulsive targets (gunshot, mortar, etc.) associated acoustic waves are of two types:

- the shock wave generated by the supersonic bullet,
- the muzzle blast arising from the gas release at the muzzle of the weapon.

For small calibre gunshot, the detection is automatically done on the first wave in time and the most energetic: the shock wave.

The physical input of the acoustic detector is the acoustic pressure measured by the microphone, while for the seismic detector, it is the particular speed measured by the geophone.

The UGS average detection performances according to the target and to the sensor are listed in the following table.

Detection range	Pedestrian	Ground vehicle	Aerial vehicle
One acoustic channel	Few tens of meters	200 m (light wheeled P4 type) 1500 m (heavy tracked)	3000 m
One seismic channel	Few tens of meters	Few tens of meters (tracked)	N/A
One acoustic array	Few tens of meters	300 m (light wheeled P4 type) 2000 m (heavy tracked)	4000 m

Table 1: Typical average detection range

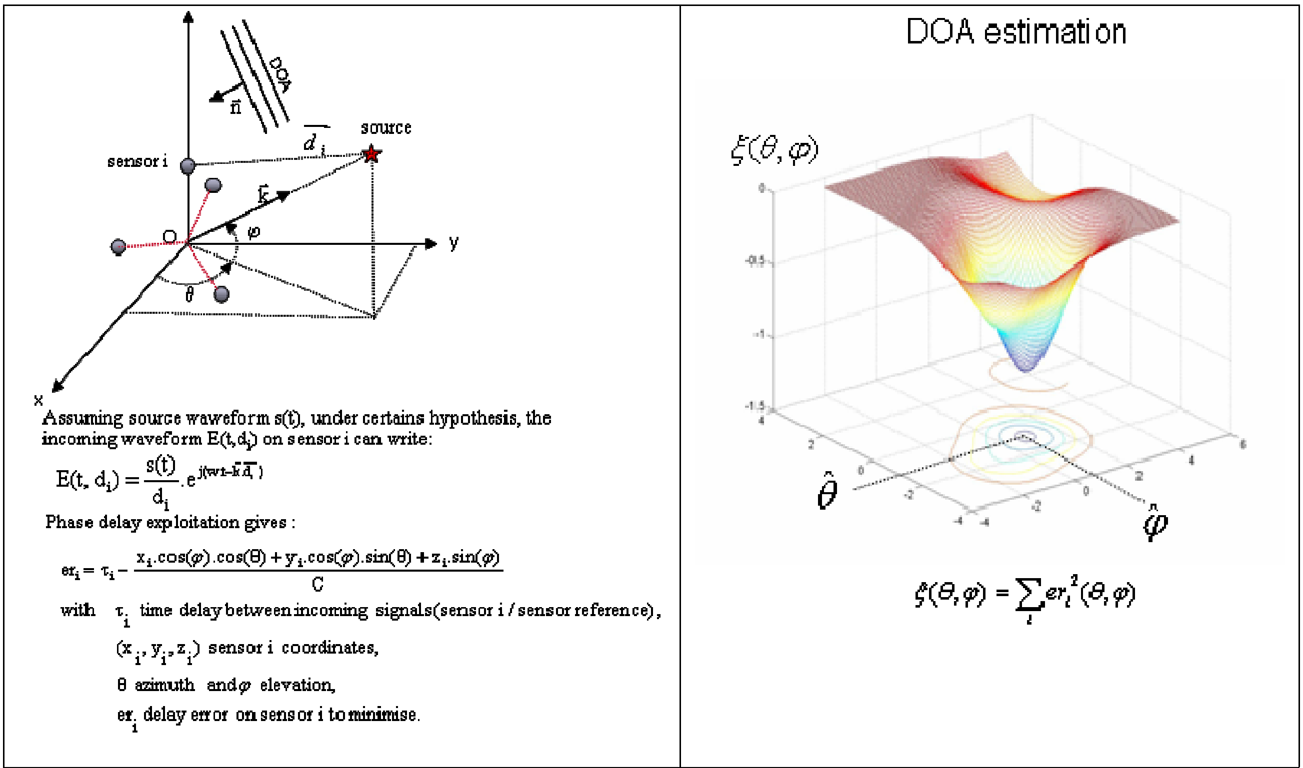
These average values can change according to the threat nature (kind of vehicle, speed, load) and to environmental and meteorological conditions.

3.2 Target localisation

The target localisation function allows estimating the geographic position of the detected threat. Often times, the source localisation is limited to the Direction Of Arrival (DOA) estimation, which gives azimuth and elevation. Otherwise, threat distance is estimated using other methods.

DOA, which mainly concerns acoustics, is estimated by array processing methods. For now twenty years, 01dB-METRAVIB has worked on well-known algorithms [1] and has developed its own algorithms. The localisation technique is based on a model exploitation that includes propagation and background noise modelling. Then, phase and statistics properties of the incoming wave on the array are exploited. Array processing may be used in time domain, as well as in frequency domain, and we distinguish beamforming techniques from high-resolution methods.

For example, in geometric 3D space (see Fig. 2), we assume a source emitting an acoustic wave s(t) and a point array sensor i with spatial coordinates $r_i = (x_i\ y_i\ z_i)^t$. On this sensor, for a wave number k, received acoustic waves E(t, d_i) may be expressed in time domain, as a function of the propagation delay d_i/C, where d_i is the source sensor distance and C the sound propagation speed. Then, the localisation problem is solved by using many sensors and minimising the propagation model to an observation vector coming from all the sensors signals.



Emission/reception typical 3D mode — Localisation by minimising a parametric function

Figure 2: Localisation principle with array processing

The localisation techniques for stationary case are multi-target and allow to localise up to three vehicles with our tetrahedral acoustic array.

Several localisation algorithms have been studied and implemented. The following table presents their mains characteristics.

Method	Key element	Multi-target	Advantages	Convenient
Beamforming	Propagation delay	Yes	Simple robust	Poor resolution
Capon regularized	Minimum variance distortionless response	Yes	High Resolution Target number estimation possible from azimuth estimation	Low robustness if bad estimation of target number
Incoherent wideband MUSIC	Source orthogonal to noise subspace	Yes	High Resolution	Low robustness if bad estimation of target number
Coherent wideband MUSIC	Source orthogonal to noise subspace and focalisation	Yes	High Resolution	Low robustness if bad estimation of target number

Algorithm patented by 01dB-METRAVIB	Multidimensional function minimisation	Yes	High Resolution Target number estimation made with azimuth estimation	High numerical cost needs calculation optimisation

Table 2: Characteristics of localisation algorithms used

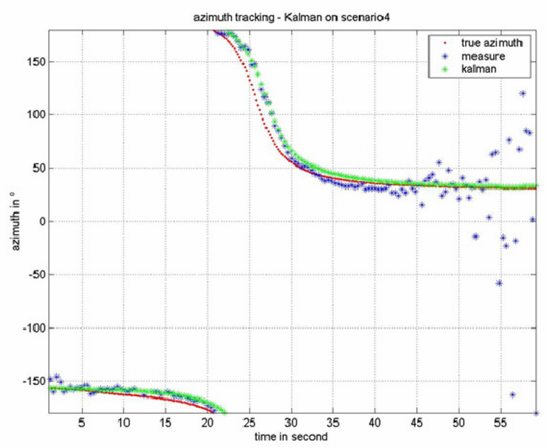
A few methods have been implemented for target distance estimation. The most efficient and robust method is the triangulation method based on many acoustics arrays. Triangulation achieved by a fusion function is available for vehicle and for gunshot.

When using a single array, capable of measuring both the acoustic signature and the wave vector, the azimuth of fire location may be estimated from the measurement of the muzzle blast wave. In addition, the difference in time of arrival between the shock wave and the muzzle blast is directly linked to the shooter distance [6].

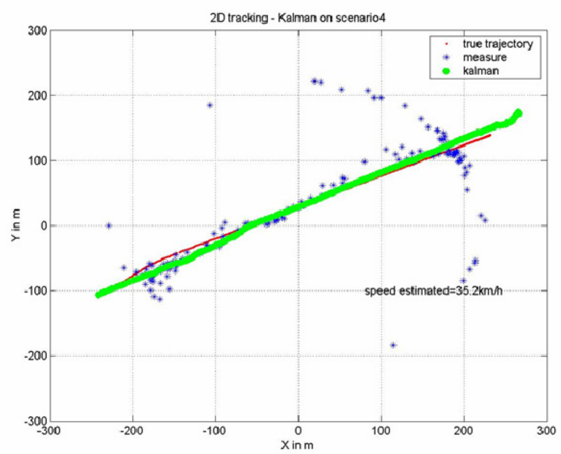
We have also shown [1] that it was possible to estimate vehicle distance by using an approximation between measurements and a propagation model in low and high frequency domains.

3.3 Target tracking techniques

Vehicle tracking consists in following the target in time while on manoeuvres and then allow to draw its trajectory. Tracking may be plotted versus azimuth or versus position (x,y) for 2D geometry when distance is also estimated. We have addressed this issue using two approaches. We have first developed a multi-target-tracking algorithm to track up to 3 vehicles in azimuth simultaneously with a single array. We have then worked on the way to improve the tracking when azimuth and distance are estimated. The method uses a recursive Kalman [3] filter assuming a linear and uniform trajectory model with a vehicle at a constant speed. Results coming from experimental data (Fig.3) confirmed this feasibility.



Azimuth tracking with Kalman



2D position tracking with Kalman

Figure 3: AMX 30 tracking using Kalman filter with a single array

3.3 Target recognition

The extraction of relevant target features is a key point to efficiently characterize signals in target recognition. This task may be viewed as a discrimination problem where the aim is to emphasize the separability of classes through a careful choice of features parameters. We have developed a recognition method running with a supervised phase that gives good results. Figure 4 presents results with 4 vehicles classes coming from the TG25 campaign. The learning base for supervised phase represents only 4% of the whole base to be recognised.

Vehicles classes

Class 1 = heavy tracked (AMX30),

Class 2 = light tracked (AMX10P),

Class 3 = heavy wheeled (VAB,
AMX10RC, TRM 2000,
TRM 10000),

Class 4 = light wheeled (P4, Pick up)

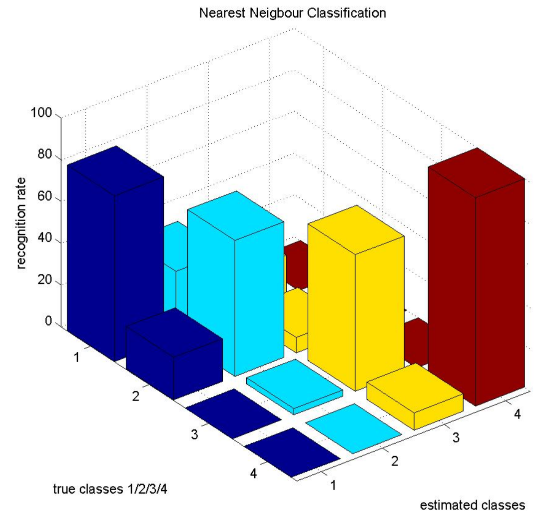


Figure 4: Recognition rate on 504 acoustics waves

3.3 Data fusion

A homogeneous fusion algorithm has been developed for three acoustics arrays dedicated to gunshot detection and localisation. This approach allows significant improvement of performance gunshot localisation (azimuth and distance) in comparison to a single acoustic array.

Acoustic array fusion is ensured by the central PC after reception of azimuth and distance results from each individual acoustic array. Then, the fusion algorithm determines the most precise location and detection estimated with a minimal mean squares error, according to the error range of each method.

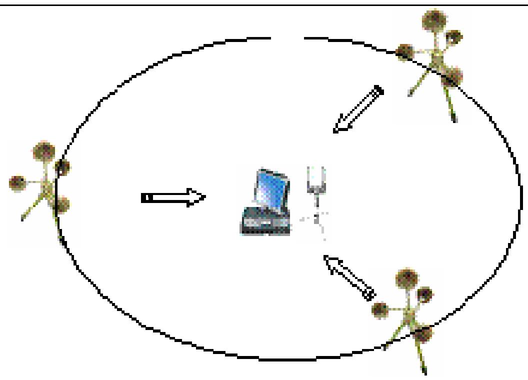


Figure 5: Data fusion with 3 acoustics arrays

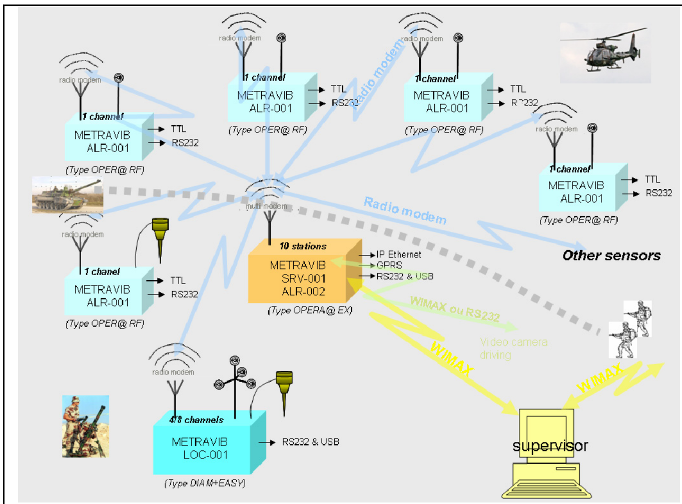
4.0 CLUSTER ORGANISATION

For area protection and information missions, our company has been developing an acoustic concept based on UGS organised in cluster (Fig. 6). The sensors cluster combines the previous multi-sensor developments and the above advanced signal processing.

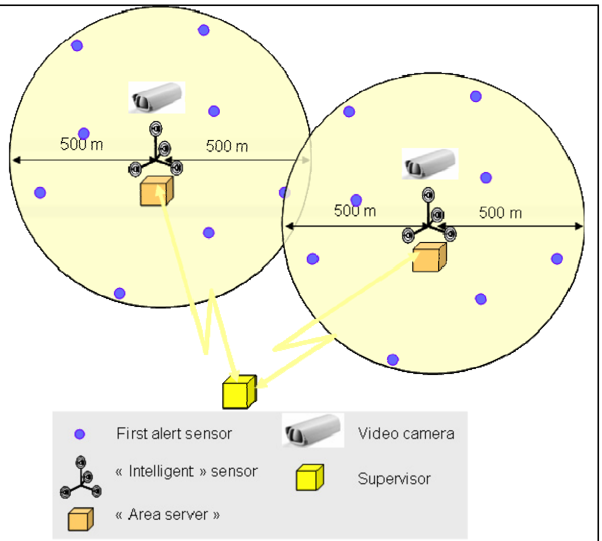
Each cluster is consists of a suite of acoustic or seismic sensors and of a video camera distributed over the controlled zone. All these sensors are interconnected with a radio-modem network and can transfer their information to the “area server” .The “Area server” collects all local sensor detection data for a cluster and performs detection fusion to locate, track and recognise threats on the cluster area. Then the system transmits cluster information to the supervisor that manages many clusters. A cluster is mainly composed of first alert sensors connected to a microphone or a geophone used for threat detection and of one or two “intelligent” sensors connected to an acoustic array for threat localisation. A video camera, driven by the “area server”, may be cued to the detected threat for visual identification.

A cluster can control a zone of 1 km^2. Then, to cover zones up to 10 km^2, several clusters can be interconnected and controlled by a supervisor. The concept of acoustic area protection is modular and can be extended for the survey of a greater zone and opened to multi-sensors in order to be coupled with complementary sensors (passive infrared, camera optic, and radar).

The basic purpose of the investigation system is to detect, locate, track, classify and report potential threats in real time. These are personnel, gunshot (sniper and mortar fire), ground vehicle (wheeled and tracked) and aerial vehicle (helicopter and plan) activities within the area of deployment.



Acoustic and seismic sensor cluster



Area protection with many clusters

Figure 6: Concept solution of a new acoustic-seismic survey system

Deployment of clusters sensors is controlled by operational requirements depending on the scenario and on the context. Installation kits allow installing the sensors in various configurations (building, open area …).

5.0 CONCLUSION

The company has developed a multi-sensor technology associated with signal processing that can henceforth be dedicated to area protection. Modular and open design of multi-sensor network is the selected solution. This concept is based on all our experience in acoustic threat detection systems.

These automatic surveillance systems allow detecting, localising and classifying main battlefield targets (gunshot, mortars, rockets (RPG), vehicle, helicopter, and soldier). They are ideal tools for infantry units, Special Forces, reconnaissance patrols, peacekeeping forces and surveillance of sensitive sites.

For homeland security, developed systems can be used for border surveillance, as well as for securing events and installations against terrorist attacks. Various applications include international conferences and popular meetings, building protection, airport protection, vehicle protection (VIPs, convoys, etc.).

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